Optimized EUV Mask Absorber Stack for Improved Imaging by Reducing Crystallinity of Alternative Absorber Materials

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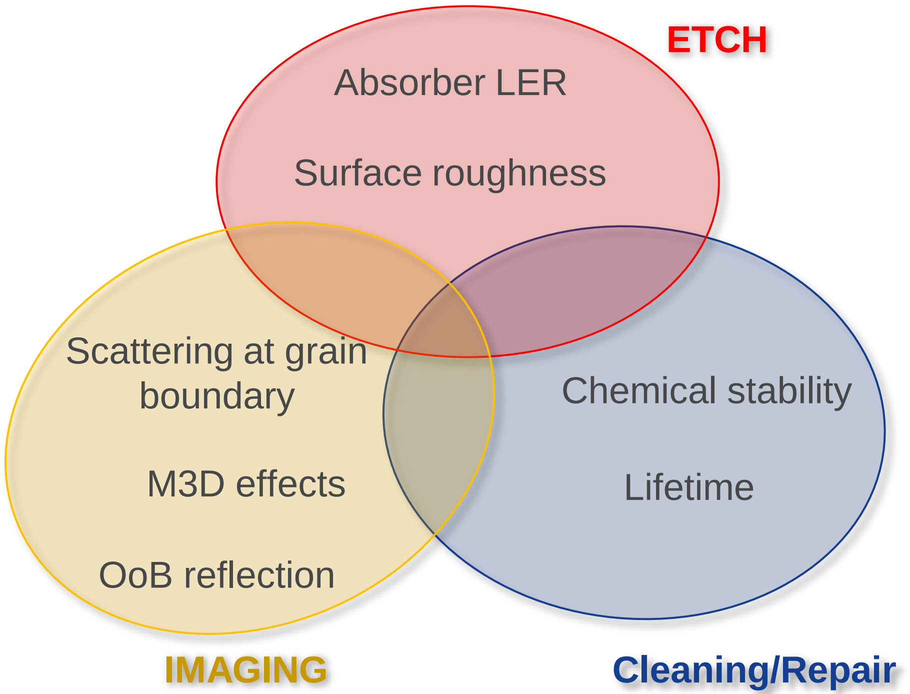
EUVL SYMPOSIUM 2016 – Hiroshima, JAPAN – October 24, 2016

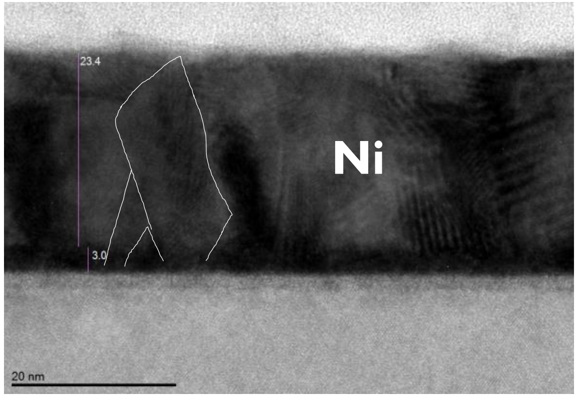
IS CRYSTALLINITY IMPORTANT?

Crystallinity can be looked at from different perspectives

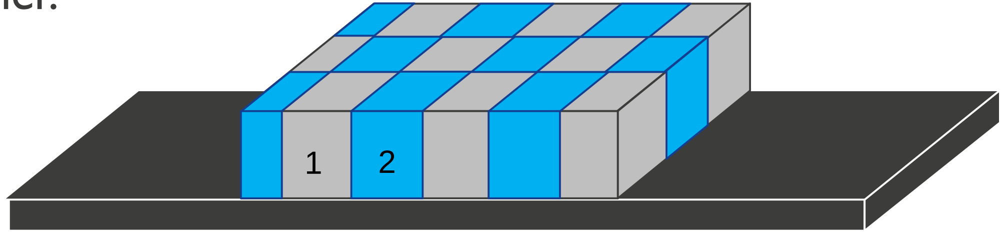


CRYSTALLINITY

Imaging modeling – Setting up the model



- Columnar grains of ~10nm diameter spanning the full layer. Grains have slightly different optical constants from each other.



- Optical constants based on material density. Amorphous Ni density taken as 90% of crystalline Ni density*.

	ρ [g/cm³]	$n = 1 - c_1 \, . \, \rho$	$k = - c_2 \, . \, \rho$
1) $Ni_{crystal}$	8.908	0.948	-0.0727
2) Ni_{amorph}	8.017	0.953	-0.0655

* T.Q. Dong et al, Thin Solid Films, 2013

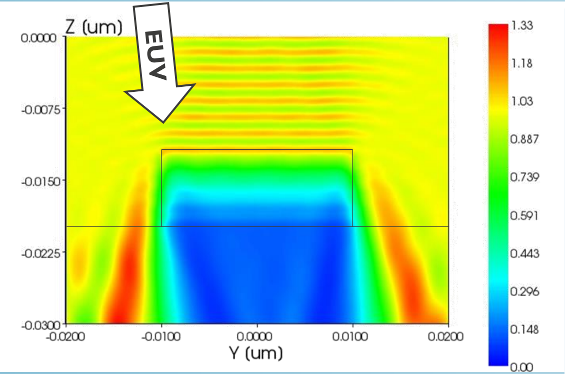
CRYSTALLINITY

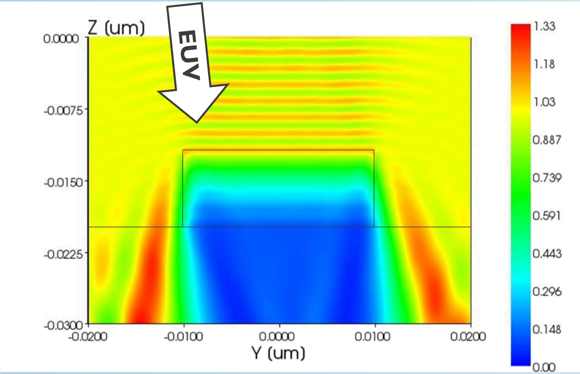
Imaging modeling – Nearfield images

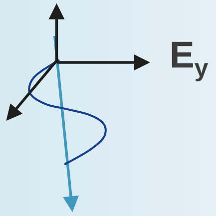
40nm HP – Horizontal Line
4x reduction
No ML mirror

Multi-grain Nickel | **Single grain Nickel**

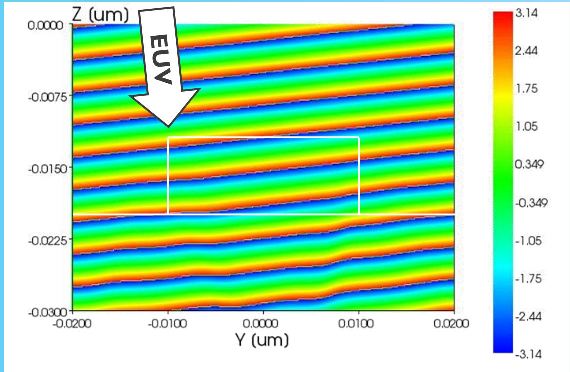
Nearfield Amplitude E_y

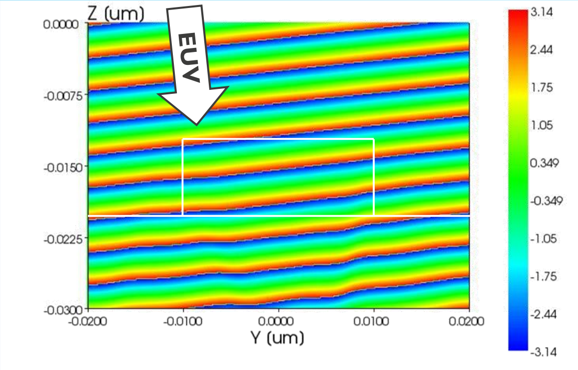






Nearfield Phase E_y





Seemingly no difference in the dominant E_y dimension.

CRYSTALLINITY

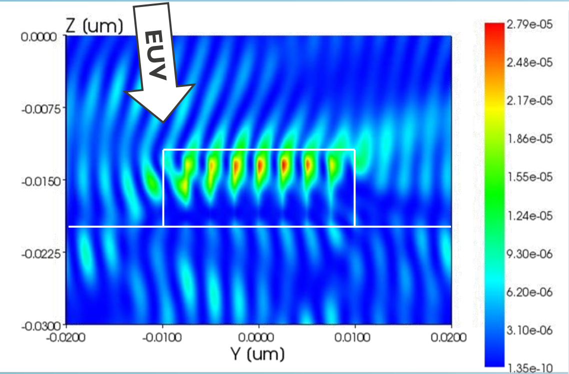
Imaging modeling – Nearfield images

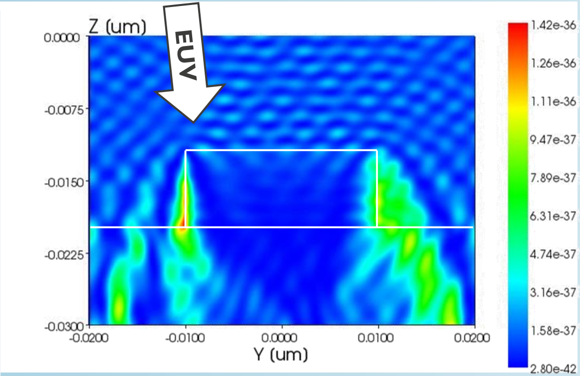
40nm HP – Horizontal Line
4x reduction
No ML mirror

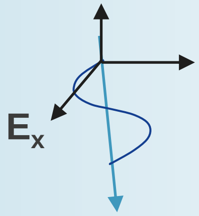
Multi-grain Nickel | **Single grain Nickel**

Nearfield Amplitude E_x

! Different scale

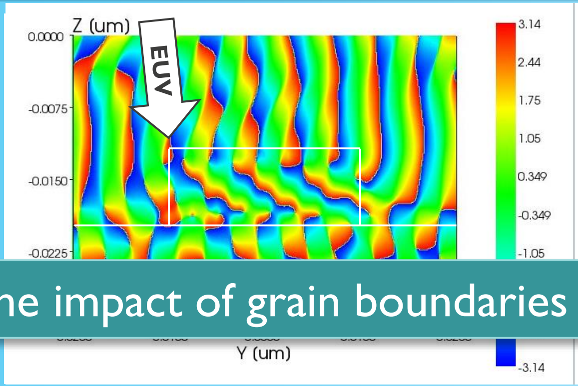


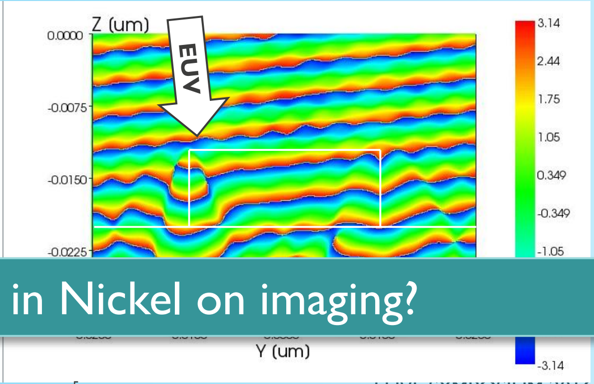




Grain boundary effect in the E_x dimension.

Nearfield Phase E_x





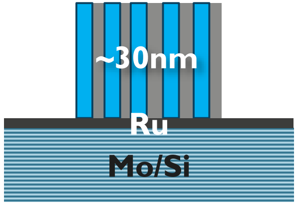
Relatively much larger than the single grain case, but absolute amplitude is small.

How big is the impact of grain boundaries in Nickel on imaging?

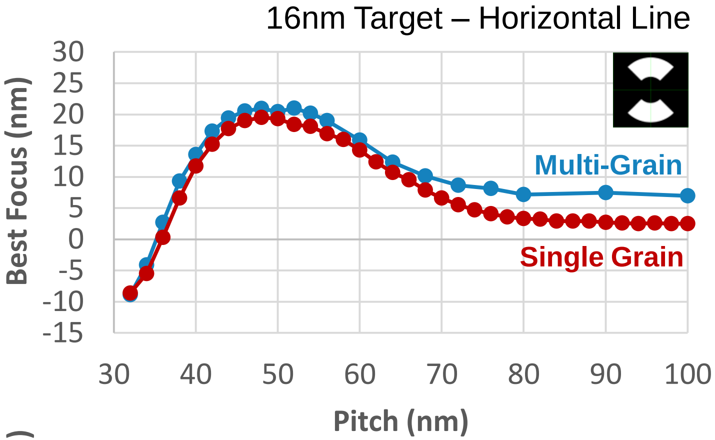
CRYSTALLINITY

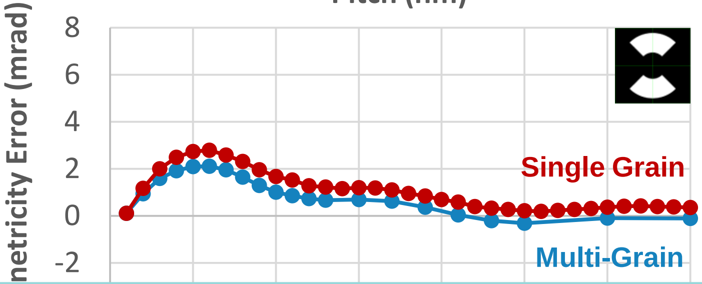
Imaging Impact (Lines)

Single Grain Ni absorber



Multi-grain Ni absorber





Small imaging impact by grain boundaries for investigated features.

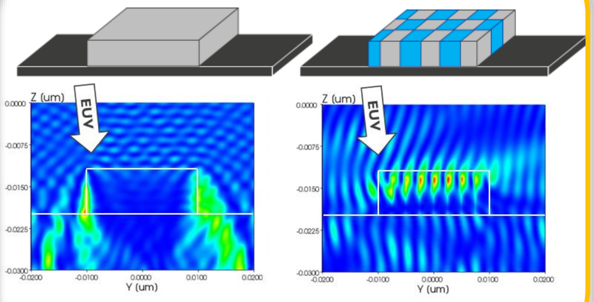
Pitch (nm)

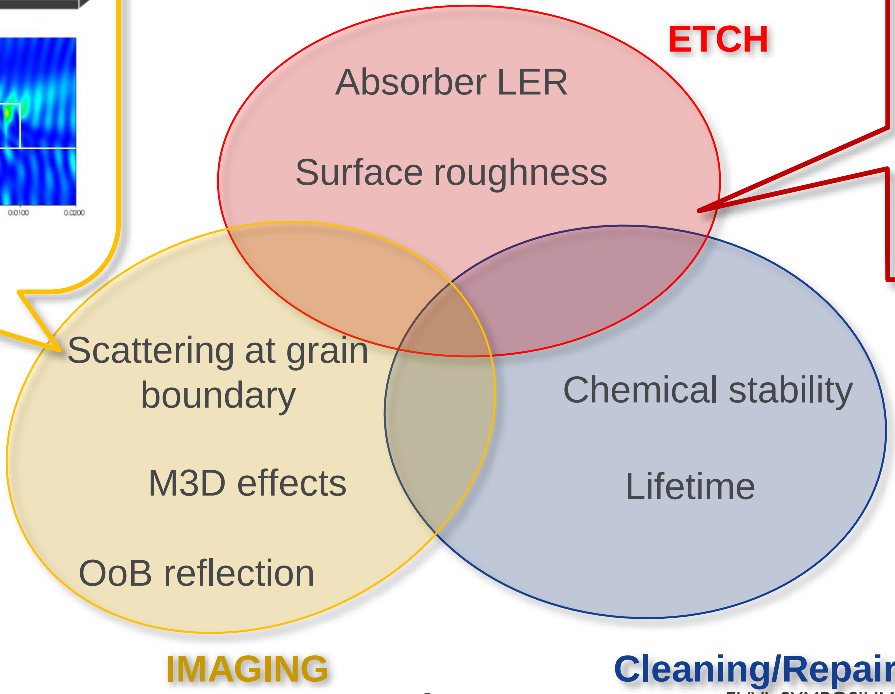
IS CRYSTALLINITY IMPORTANT?

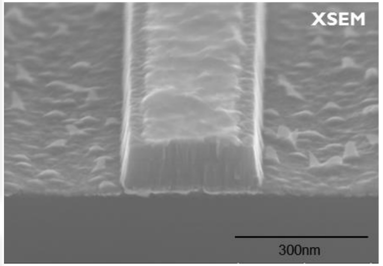
Crystallinity can be looked at from different perspectives

Single grain

Multi-grain







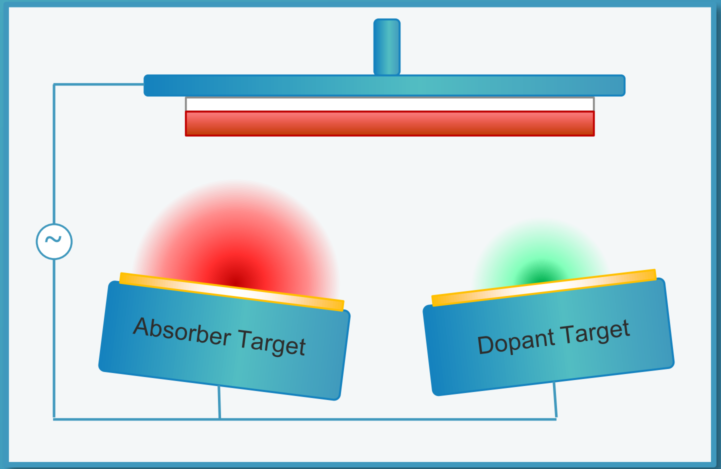
V.Philipsen
EUVL Symposium 2016

CRYSTALLINITY

MITIGATION STRATEGIES

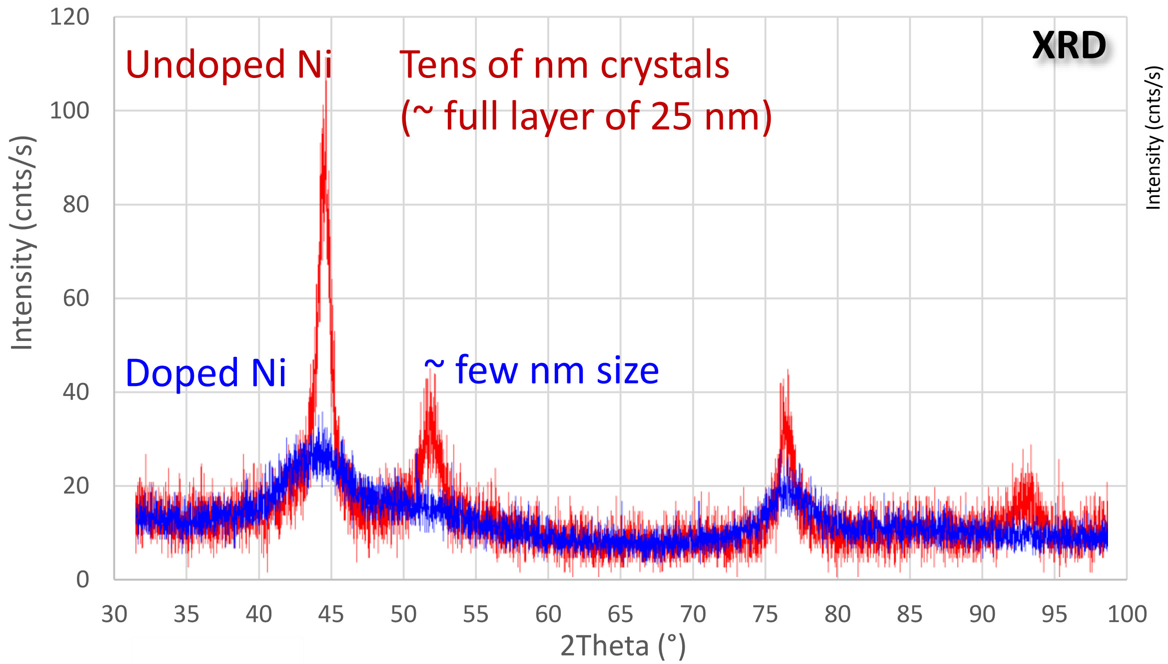
- Doped absorber material
  - Co-sputtering of a dominant element with a dopant element → breaking of crystal lattice during deposition while preserving the density of dominant element
- Alloyed absorber material
  - Co-sputtering of two or more elements with different atomic sizes, hereby breaking the crystal lattice and forming thin film metallic glass (amorphous metal)
- Multilayer absorber stack
  - Using a second material as spacer to limit the layer thickness of the absorber material, hereby reducing crystal growth.
  - Multilayer structure allows for tuning the imaging behavior.

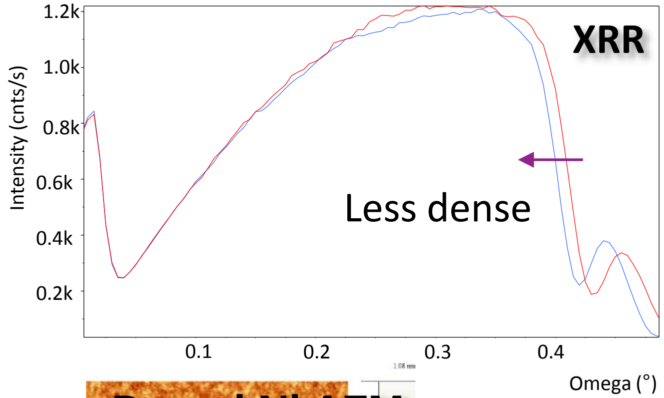
DOPED ABSORBER MATERIAL

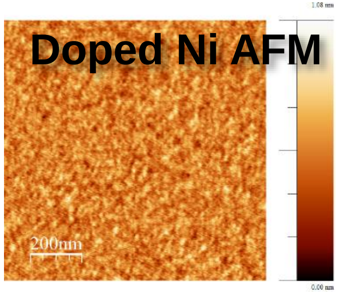


DOPED NICKEL ABSORBER CHARACTERIZATION

- 10at% doped Ni successfully changes structure
- XRD: reduced crystallinity; XRR: reduced density; AFM: reduced roughness



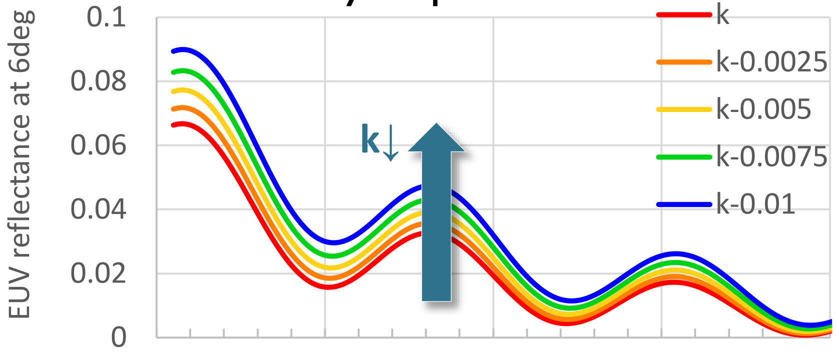


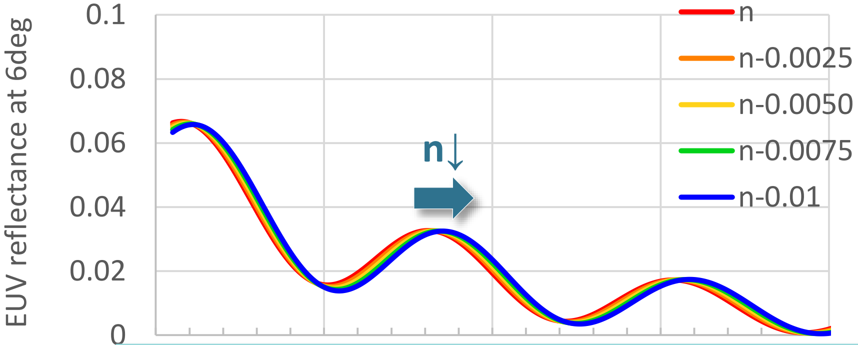


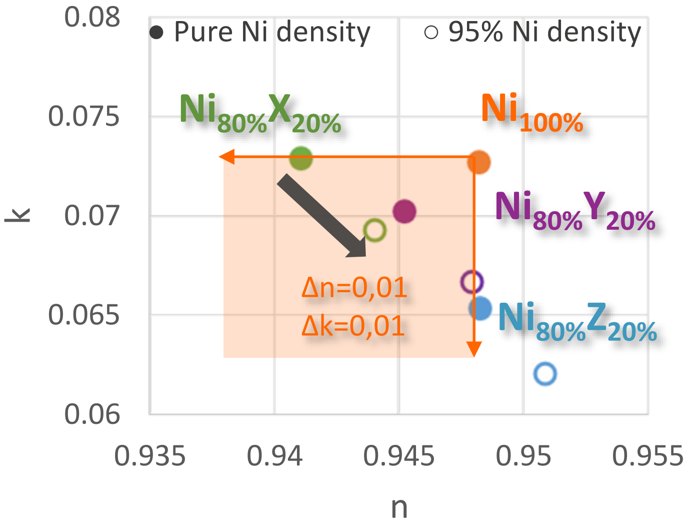
Reduced roughness (0.3 nm → 0.1 nm) after doping

DOPING SENSITIVITY SIMULATIONS

- Assume small doping content (≤20at%) with light dopant ($Z_{dopant}<Z_{absorber}$)
  → assume density doped absorber ≈ density pure absorber







Range sensitivity simulation valid for:
- 20at% doped absorber
- maximum 5% density reduction to pure absorber

Reduction of k biggest impact on EUV reflectance.

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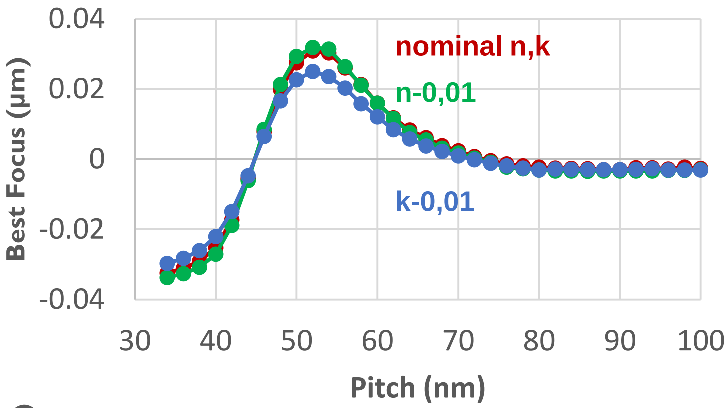
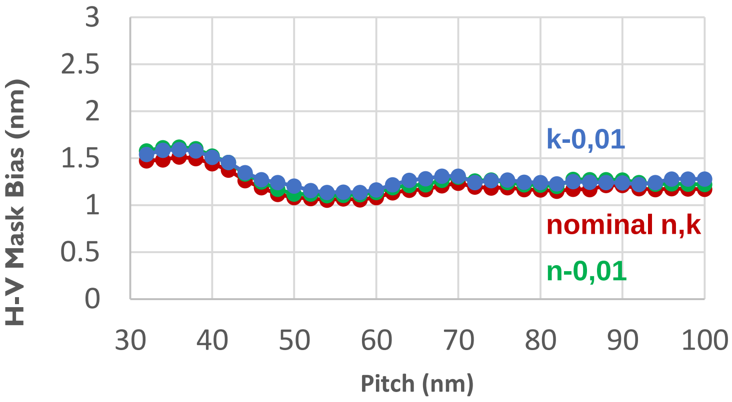
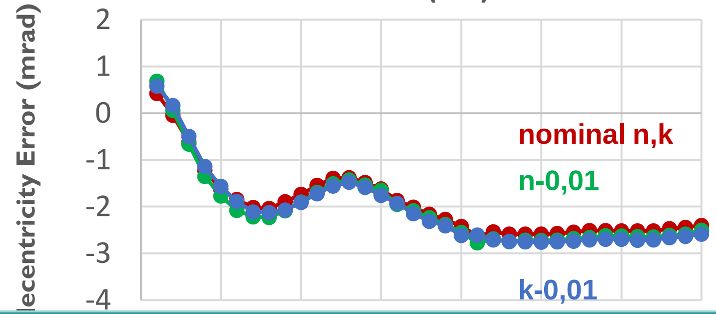
DOPING SENSITIVITY SIMULATIONS

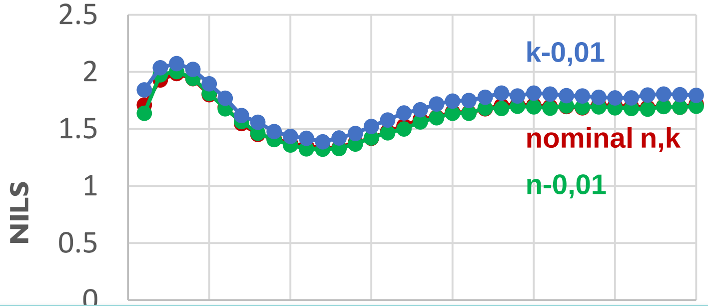
- Imaging impact and M3D results

16nm Target –Trench



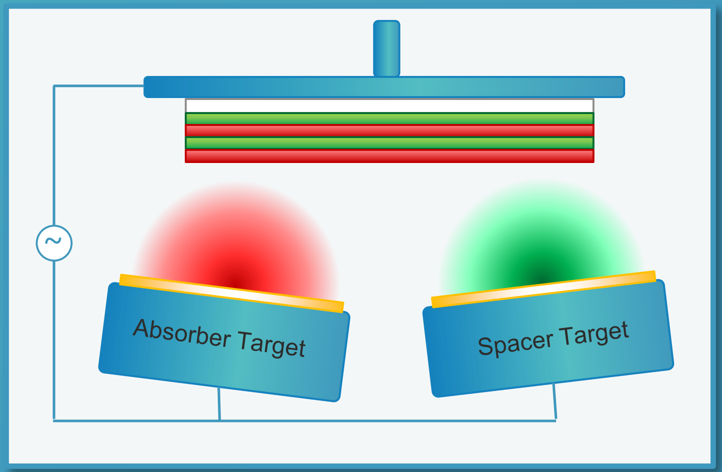






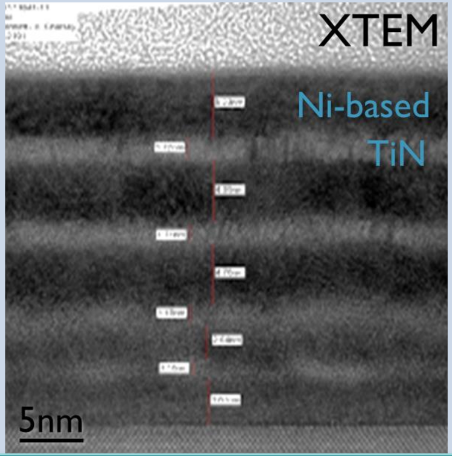
For ~30nm Ni absorber the imaging impact is not very sensitive to n&k variation by doping with a light element.

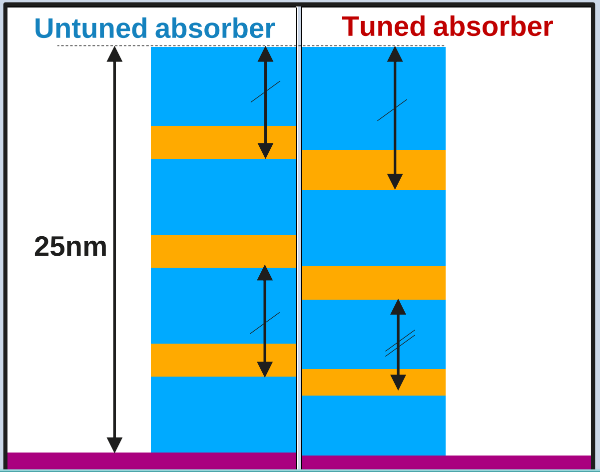
MULTILAYER ABSORBER STACK

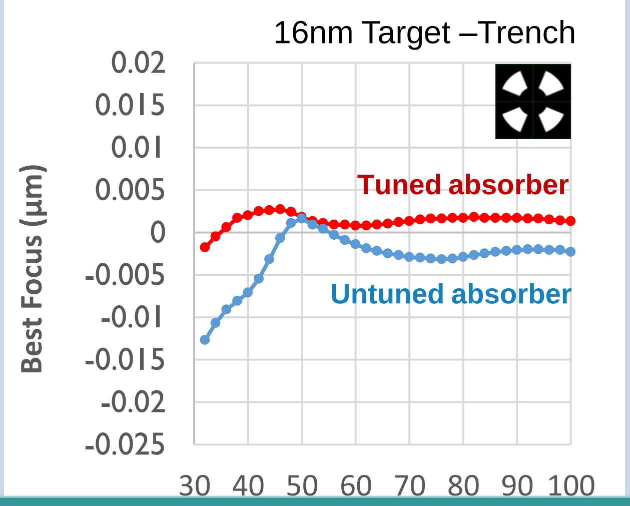


PREVIOUS WORK ON MULTILAYER ABSORBER

- Experimental Ni-based ML absorber stack deposited.
- M3D effects were modeled for untuned ML absorber stack with equal periods.
- Depending on the ML mirror response, a tuned absorber can give better M3D effects.







Tunable imaging behavior predicted with simulations. What about spacer requirements from material point-of-view?

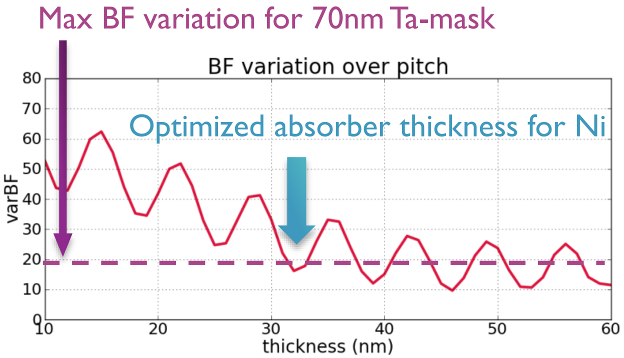
O.Wood et al, SPIE 2015
V. Luong et al, EUVL Symposium 2015

MULTILAYERED ABSORBER STACK

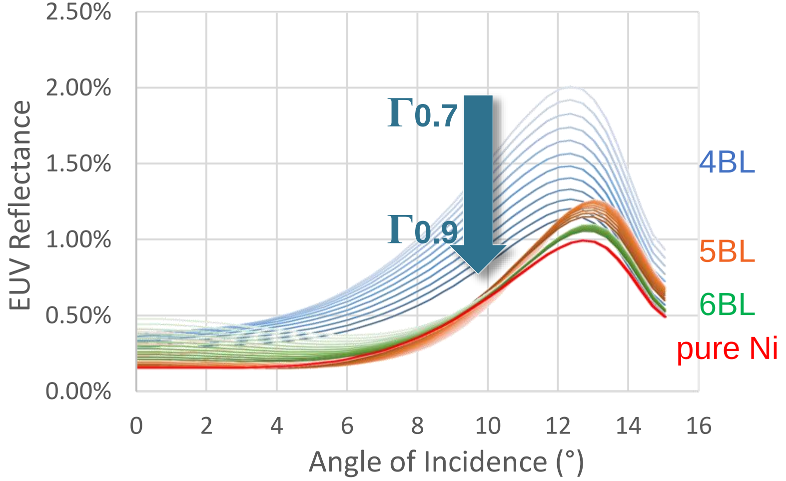
Ni/MgO ML absorber

- Spacer needs to:
  - limit absorber crystal growth
  - reduce templating effect of Ru
  - have anti-diffusion properties
- Additional advantages of MgO: slower dry etch rate than Ni, can be used as etch stop layer

- Imaging impact comparison with pure Ni absorber
  - Total thickness ~30nm for minimum BF shift in pure Ni
  - For low reflectivity:
    - 5 bilayers
    - High Γ-factor
      (= ratio of absorber versus bilayer thickness)



See V. Philipsen presentation



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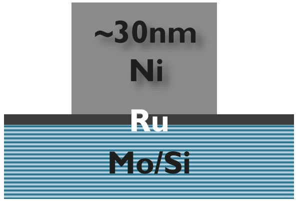
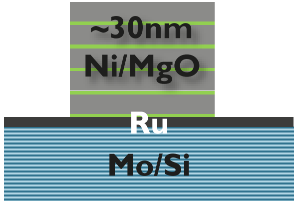
MULTILAYERED ABSORBER STACK

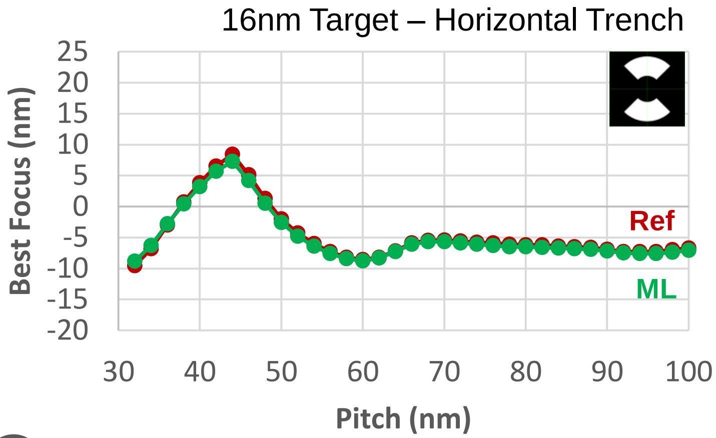
Ni/MgO ML absorber – Imaging impact

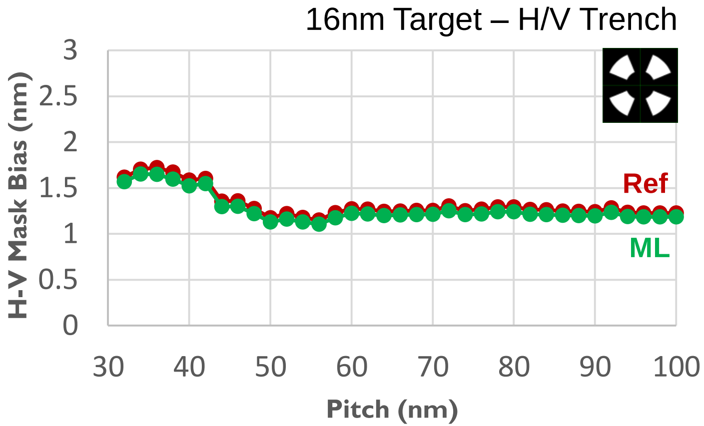


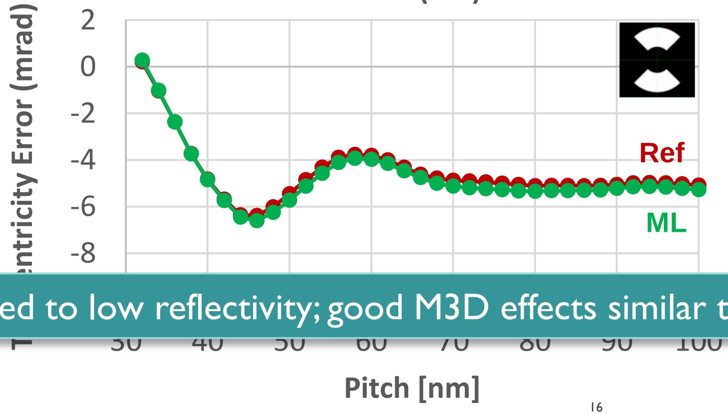
Ref pure Ni absorber



ML Ni/MgO absorber
5 BiLayers Ni/MgO
Γ= 0.84





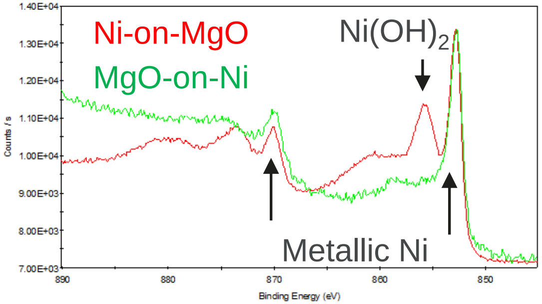


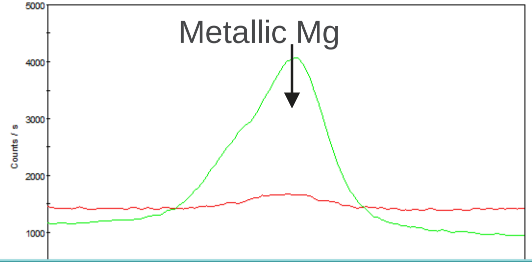
ML absorber tuned to low reflectivity; good M3D effects similar to single metal absorber thanks to high Γ-factor.

MULTILAYERED ABSORBER STACK

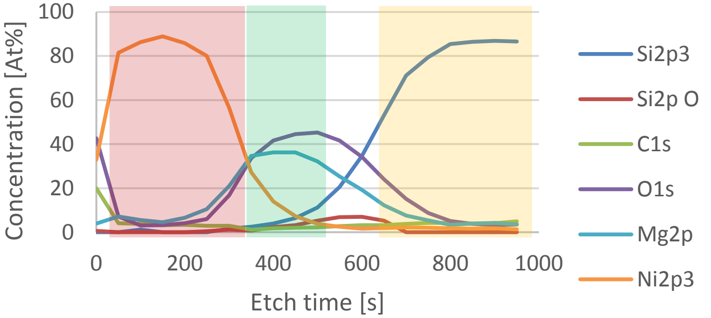
Ni/MgO ML absorber – Single bilayer characterization

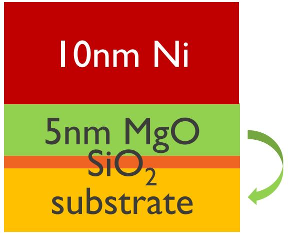
XPS: Chemical state at interface



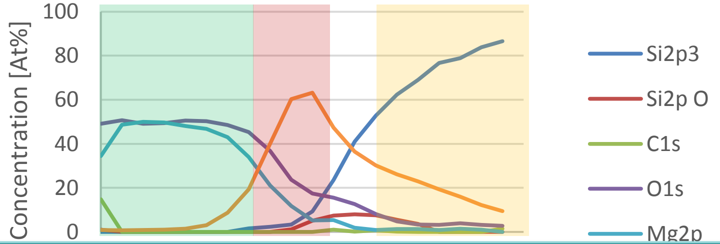


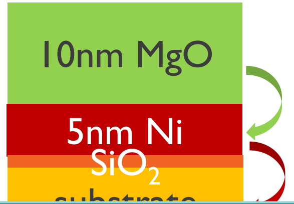
XPS through depth





Ni-on-MgO





Limited diffusion into MgO = good barrier material.

NiO and MgO peaks under noise levels.

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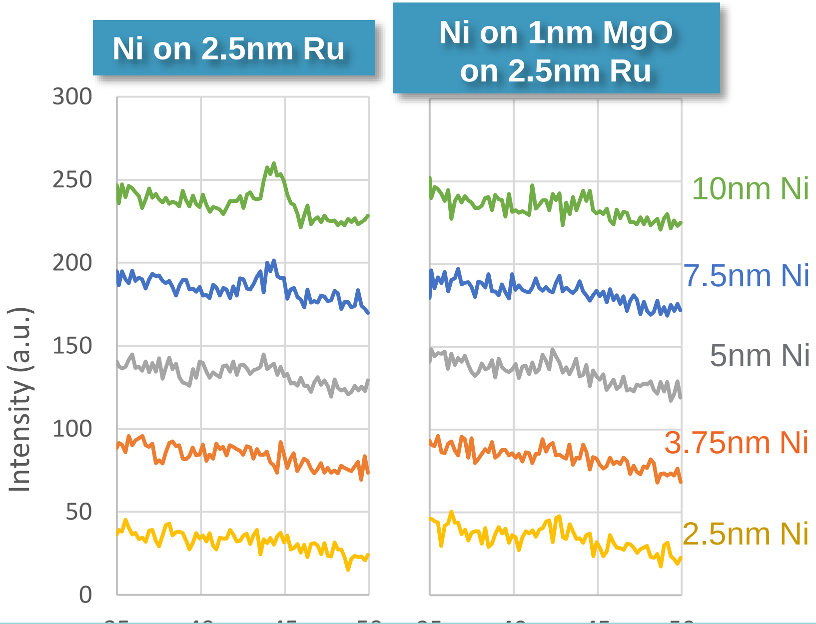
MULTILAYERED ABSORBER STACK

Ni/MgO ML absorber – Single bilayer characterization

- XRD: Ru templating is still present at 7.5nm Ni. Peak blends in with noise level for thinner Ni. No visible peaks with MgO spacer.



MgO spacer successfully reduces Ni crystal size.

CONCLUSION

- The work until now has achieved
  - Single metal Ni absorber is optimal imaging-wise, but challenging for processing
  - We explore some mitigation strategies from a material point-of-view (experimentally) and from imaging point-of-view (simulation)
  - Doped absorber optically very similar to single metal absorber
  - Multilayer stack with MgO spacer reduces crystallization and can be beneficial for processing; optically it's also very similar to single metal absorber
- Next steps
  - Exploring alloyed absorber material
  - Patterning Ni/MgO ML absorber and doped absorber

THANK YOU

Sven Van Elshocht, Christoph Adelmann, Sofie Mertens, imec / Thin Films
Hilde Tielens, imec / FPE
Thierry Conard, Hugo Bender, Olivier Richard, imec / MCA
Laurent Souriau, imec / ETCH

Weimin Gao, Synopsys

Emily Gallagher, Rik Jonckheere, Kurt Ronse, Nadia Vandenbroeck, imec / AP
Prof. Dr. Marc Heyns, imec-KULeuven (PhD-promotor)

and Thank You for listening!

ACKNOWLEDGEMENTS

SeNaTe

ECSEL Joint Undertaking
Electronic Components and Systems for European Leadership

This project has received funding from the Electronic Component Systems for European Leadership Undertaking under grant agreement number 662338. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Netherlands, France, Belgium, Germany, Czech Republic, Austria, Hungary, Israel.